

# **WATER COLUMN VARIABILITY IN COASTAL REGIONS**

Dana R. Kester  
Graduate School of Oceanography  
University of Rhode Island  
Narragansett, RI 02882  
Tel: 401-874-6527 Fax: 401-874-6818 E-Mail: dkester@gso.uri.edu

Award # N000149410635

## **LONG TERM GOALS**

The long term goal of this project is to obtain a quantitative understanding of the physical, chemical, and biological processes that produce variability in coastal waters. The processes being investigated include the atmospheric forcing of water column properties, the effects of physical mixing and circulation, the biological uptake and release of nutrients and gases, and chemical reactions at phase boundaries. The information derived from this research will provide the basis to construct quantitative models of a range of properties in coastal waters and their variability.

## **OBJECTIVES**

The objective of this research is to understand the causes of temporal and spatial variability in coastal waters. Of primary interest are oxygen, carbon dioxide, suspended particulate matter (SPM), chlorophyll, temperature, and salinity. These properties were selected because their variability encompasses a wide range of processes such as (i) *in situ* photosynthesis, respiration, and decomposition of organic matter, (ii) air-sea gas exchange, (iii) response to meteorological conditions (solar radiation, wind velocity, heat exchange), (iv) physical processes such as tidal mixing, stratification, water mass variations, (v) runoff from land, and (vi) anthropogenic inputs.

## **APPROACH**

We are combining *in situ* sensor measurements with satellite remote sensing. Time series observations have been maintained near the entrance of Narragansett Bay since 1995. A spar buoy was deployed near the middle of the Bay in January 1997 with multi-depth sensors to measure changes in stratification and the vertical gradients. A technique was devised to tow the sensors from a small boat to determine lateral variability, and to obtain sections of vertical profiles. A variety of methods are used to analyze the high-resolution observations and to model the processes that cause variability in coastal waters.

## **WORK COMPLETED**

Magnuson, Woods, and Kester obtained a year-long continuous time-series of variability near the entrance of Narragansett Bay at the GSO pier with water column and meteorological measurements every ten minutes. Magnuson and Kester completed a study of the Total

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 1997</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1997 to 00-00-1997</b>	
4. TITLE AND SUBTITLE <b>Water Column Variability in Coastal Regions</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of Rhode Island, Graduate School of Oceanography, Narragansett, RI, 02882</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

Alkalinity to salinity ratio (TA/S) in waters of the Bay and the adjacent U.S. shelf and slope waters. Using this ratio we calculated the total CO<sub>2</sub> concentration, the partial pressure of CO<sub>2</sub>, and the air-sea exchange of CO<sub>2</sub> from the *in situ* temperature, conductivity, and pH sensors. In January 1997 Andrews, Woods, and Kester deployed a spar buoy at a central location in Narragansett Bay to obtain time-series variations at multiple depths (1, 4, and 12 meters) to determine changes in stratification. Swanson (1997) completed an M.S. thesis in which high-resolution time-series of chlorophyll fluorescence was investigated at the GSO pier. Sieburth and Kester developed the Horizontal Deployment Apparatus for the sensor sondes. Kester and Woods began a year-long intensive study of coastal variability in the western Pacific with colleagues in Hong Kong.

## RESULTS

The GSO pier time-series has demonstrated the relative importance of various processes that cause physical, chemical, and biological variability near the entrance of Narragansett Bay. The effects of solar radiation, wind velocity, lunar cycle tidal amplitudes, storms, and exchange with offshore waters are seen in the temperature, salinity, oxygen, and P<sub>CO2</sub> variations. The magnitudes of variability over seasonal to diel and shorter time-scales have been determined. Net daily fluxes of oxygen and carbon dioxide gas exchange have been analyzed. The characteristics of the 1997 winter-spring bloom were resolved in detail.

The underway measurements with towed sensor systems along with measurements of the TA/S ratio in Gulf Stream and coastal waters provided a means to determine gas concentrations and fluxes in the Gulf Stream, across a warm core ring, and across the continental slope and shelf south of Narragansett Bay (Magnuson and Kester, 1997a).

The TA/S ratios in coastal waters, and their use to determine CO<sub>2</sub> system variables resulted in the preparation of two manuscripts for publication (Magnuson and Kester, 1997b, 1997c). An improved procedure for alkalinity titrations was devised in which the Gran plot endpoint becomes better defined with the purging of the CO<sub>2</sub> gas that builds up as seawater is acidified. We established the TA/S ratio for Narragansett Bay waters over an annual cycle.

The multi-depth time-series in central Narragansett Bay obtained with the spar buoy system produced major new insights into vertical stratification in the Bay (Andrews, 1997). During January 1997 the surface water temperature cooled from 6°C to less than 1°C over a two week period. The bottom waters also decreased in temperature during this period, but they lagged the surface cooling so that for about 50% of the time they were warmer (by about 1°C) and more saline than the surface. We observed a series of stratification events, several days in duration, that were broken up by storm and tidal mixing events. Vertical oxygen saturation gradients developed during each stratification event, showing the rapid response of phytoplankton to these periods of stratification. The spring warming of the Bay and importance of injection of offshore waters at depth into the Bay were seen in this data set during the period March through May 1997.

Fox and Kester (1997) examined sea surface temperature variations on the continental shelf of the northeastern U.S. using AVHRR satellite imagery with 1 km resolution. The satellite data

were verified with NOAA offshore buoy surface temperatures; underway ship-of-opportunity measurements were used to characterize a region of upwelling or intensive vertical mixing on the Nantucket Shoals that was revealed by the satellite images. Woods and Kester used an (SPM) algorithm to identify episodic features of high SPM reflectance near Nantucket Island.

## **IMPACT**

Understanding the causes of variability in coastal waters provides a basis to model it and to characterize it rapidly and efficiently. The approach being used is widely applicable to coastal regions throughout the world. Scientifically we are gaining new knowledge about variability in coastal waters. We have devised methods to measure variability of water properties that can reveal the nature and dynamics of coastal environments. This will be useful in operations where information on coastal water properties and their variability is required. This research also provides an improved distinction between natural variability and changes due to human activities.

## **TRANSITIONS**

During FY97 this project led to commercialization of new technology and to applications in the western Pacific region. At the ONR-sponsored workshop MARCHEM '93 Kester (1993) summarized problems associated with under-sampling chemical variability in the ocean. A dialog was initiated with Dr. John McDonald of YSI, Inc. which led to our evaluation and subsequent use of their rapid-pulse dissolved oxygen sensor, as well as other sensor systems. Since then we have worked closely with YSI and Endeco/YSI of Marion, MA on the improvements and applications of their instruments for coastal oceanographic measurements. Experiments in 1995 onboard R/V Oceanus demonstrated the feasibility of towing the sensor sondes to obtain high resolution spatial measurements. During FY96 and FY97 our studies have been conducted in close cooperation with Professor Emeritus John McN. Sieburth, who upon retiring from the GSO faculty in 1991, selected and set up a small and efficient coastal research vessel that is 24 feet in length. His R/V Melanitta has been a valuable resource for our research.

Our investigations required a new approach to measure lateral variability in coastal waters. Patchiness in plankton populations has been recognized for many years, and we found "patchiness" in 1-km resolution AVHRR SST images on a range of spatial scales from about 2.5 to 44 km in northeastern U.S. coastal and continental shelf waters. While there are several towable platforms such as the Canadian Batfish and the British AquaShuttle, they are expensive and require special winch systems. We devised a simple system to tow the sensor sondes, and to switch modes of operation from profiling at fixed stations to underway towing during transits. Sieburth developed a prototype HDA (Horizontal Deployment Apparatus) for the autonomous sensor sondes. Endeco/YSI has entered into an agreement with Sieburth to commercialize the HDA and make it part of their product line. The HDA was exhibited at the Oceans 97 in Halifax, Nova Scotia in October 1997. This research, and our collaboration with Sieburth, resulted in an inexpensive means to obtain underway physical and chemical measurements from a small boat.

The technologies we are using are highly portable. In July 1996 Kester began collaborative work

with investigators at the Hong Kong University of Science and Technology (HKUST). The sensor sondes, a laptop computer, and the HDA were easily transported to Hong Kong as hand luggage for field experiments in Hong Kong and nearby waters. HKUST established a satellite receiving station in 1995 in anticipation of second-generation ocean color remote sensing. They obtain 1-km resolution AVHRR and SeaWiFS imagery in the western Pacific from the Bo Hai to Indonesia. We have begun a joint study with the investigators at HKUST to investigate variability in their region by coupling the *in situ* and remote sensing observations. In May 1997 Kester visited the Korea Oceanographic Research and Development Institute (KORDI) to work with Dr. Dong Young Lee on equipping a ship-of-opportunity vessel with a sonde for surface measurements during regular transits of the Yellow Sea between South Korea and China. The approach being used in this research can obtain information on coastal variability virtually anywhere in the world, and significant opportunities exist to carry out this type of work in the western Pacific.

## RELATED PROJECTS

During FY97 the NOAA National Marine Fisheries Service laboratory in Narragansett and the Rhode Island Department of Environmental Management initiated a program to obtain long-term systematic measurements in Narragansett Bay. They, along with funding from the NOAA National Ocean Service, have provided us with support to establish three additional buoys with sensor systems located in surface and near-bottom waters to enable observations of multi-depth time-series variability and the evolution of stratification at multiple locations within the Bay. This additional funding is also enabling us to upgrade our buoy system to include real-time data telemetry to shore and the addition of chlorophyll fluorescence sensors on the buoys.

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